Advanced Materials

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Structural, High Value Carbon and Hydrogen from Natural Gas

1/12/2022

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Structural, High Value Carbon and Hydrogen from Natural Gas

PI: Dave Gailus, dgailus@nanocomptech.com Nanocomp Technologies/Huntsman Advanced Materials

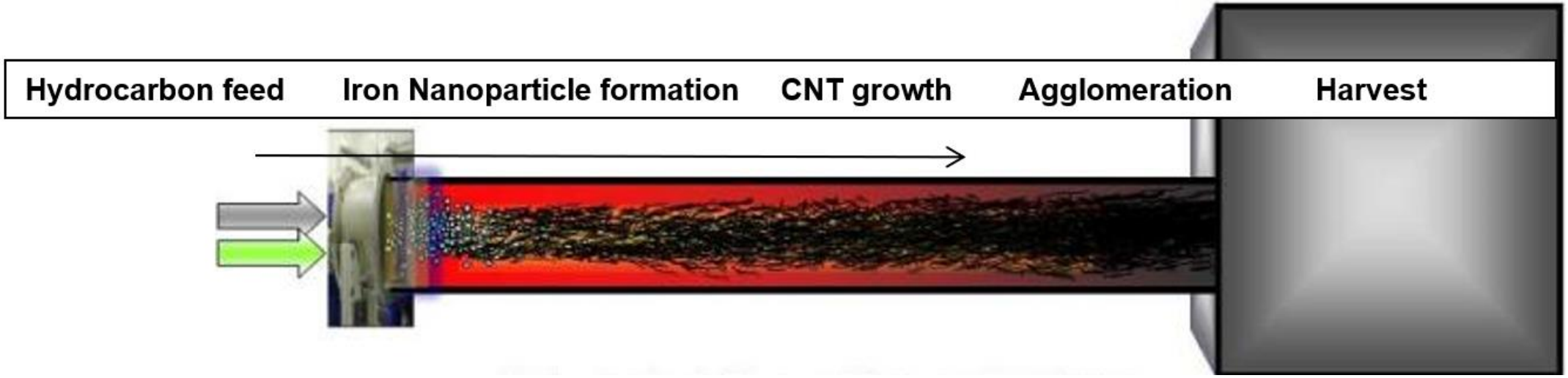
Team Members: Deepak Varshney, PhD; Jeff Littlefield; Dimitri Tselepidakis, PhD; Rachel Stephenson, PhD

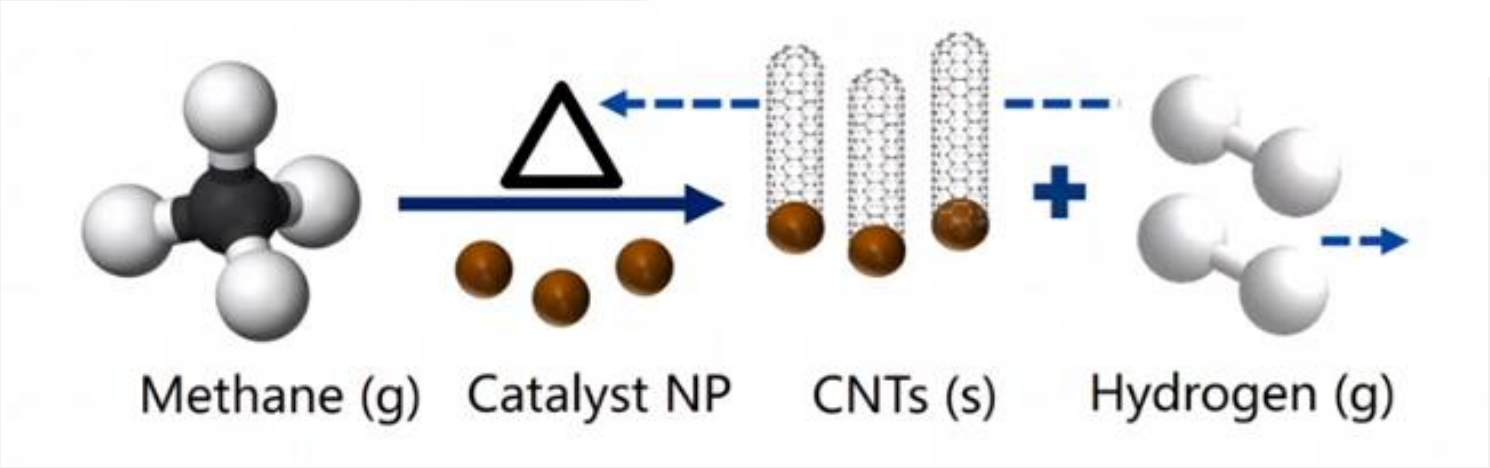
Project Vision

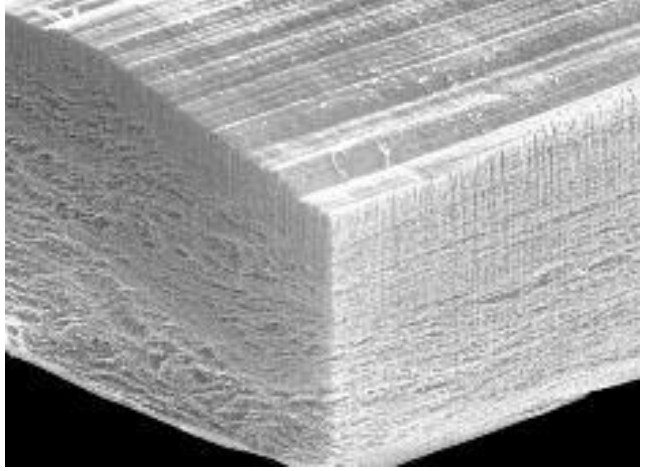
Demonstrate the potential for using the Miralon™ FCCVD process to produce hydrogen and high value carbon at the megaton scale.

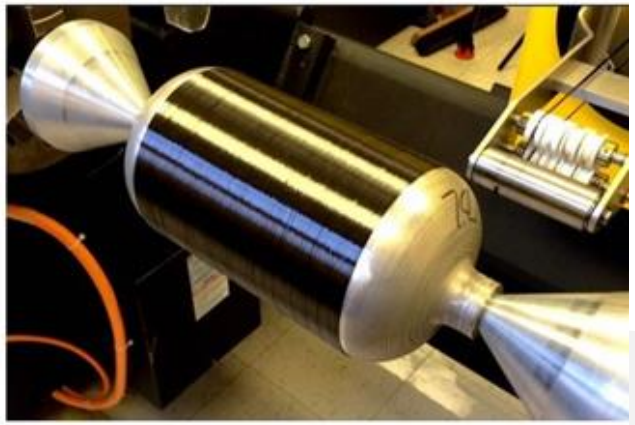
Total project cost:	$4.3M
Length	32+ mo

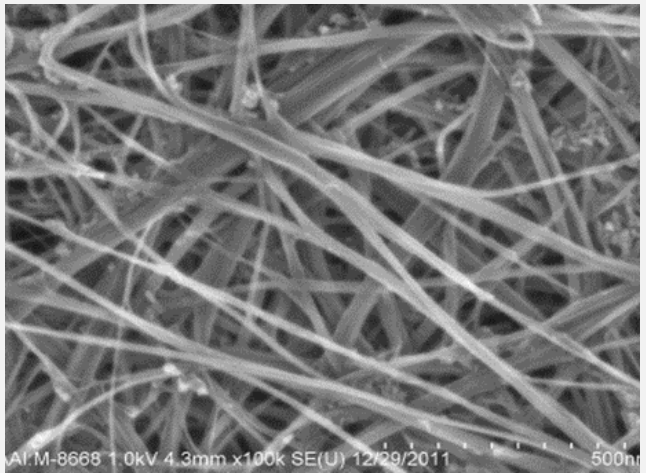
Floating Catalyst Chemical Vapor Deposition (FCCVD)











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Miralon™ FCCVD Process

- CNT's entangle and condense, acting like a polymer
- Orientation and packing density control the properties
- Strengths as high as 3.9 GPa and Modulus >200 GPa for target Space and DoD applications
- Using natural gas, hydrogen is the co-product.

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Project Objectives

Can FC-CVD be competitive with SMR with lower CO_2?

Major Tasks:

- Techno-economic and environmental analysis at the megaton scale
- Increase single pass CH_4 conversion efficiency >80%
- Demonstrate >500 MPa carbon product strength & positive H_2 production
- Improve catalyst efficiency
- Design a 1000 ton/year reactor
- Continue outreach and tech-to-market activities

Nanocomp Technologies, Inc. / Huntsman Merrimack

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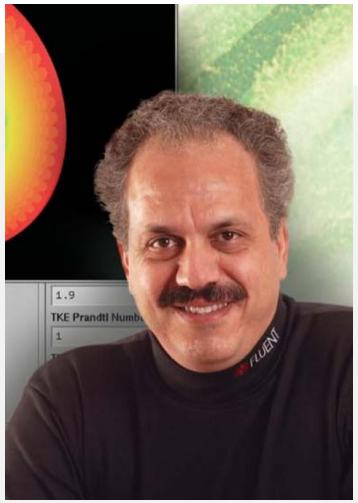
- R&D and manufacturing center for carbon nanotube production.
- 40 employees, 16 reactors on site
- Historically focused space and aerospace applications
- Recent focusing on structural carbon and H_2 at larger scales.

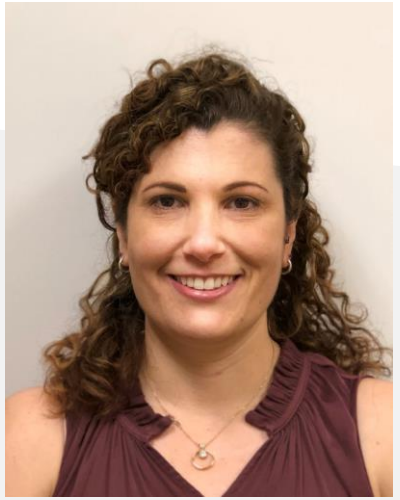
Deepak Varshney, PhD

Dave Gailus, PI



Dimitri Tselepidakis, PhD

Jeff Littlefield



Rachel Stephenson, PhD

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Elizabeth Moore, PhD

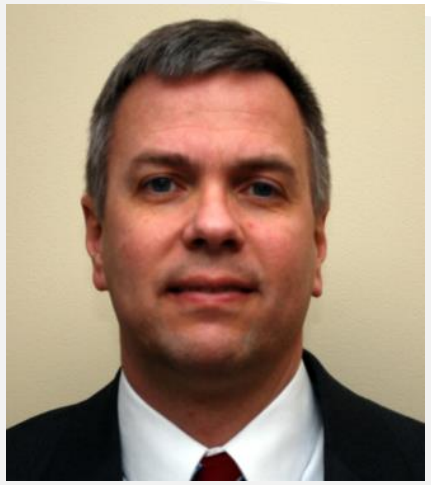
Randy Kirchain, PhD

Rich Roth, PhD

Dave Steckler, Impact Technologies, Inc.

Alain Bourhis, ScD
Impact Technologies

Our Consulting Team



Steve Strand, PhD

Steve LeViness, PhD

Warren Knoff, PhD,
Pi Orbital Consultancy

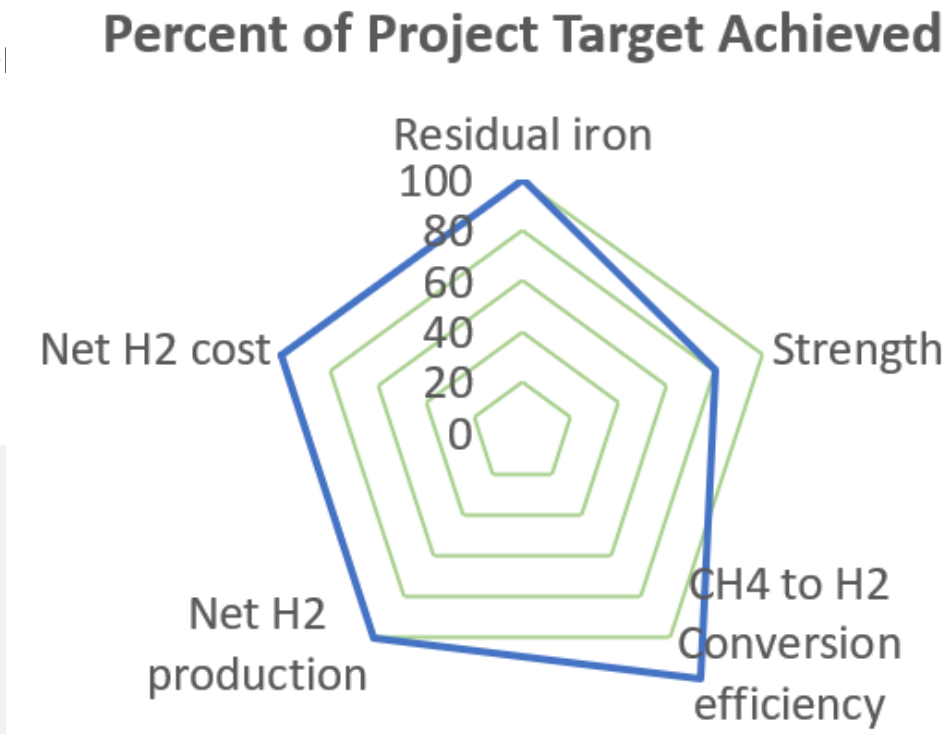
Frank Ross, PhD

Mark Banash, PhD
Neotericon, LLC.

Accomplishments since last year

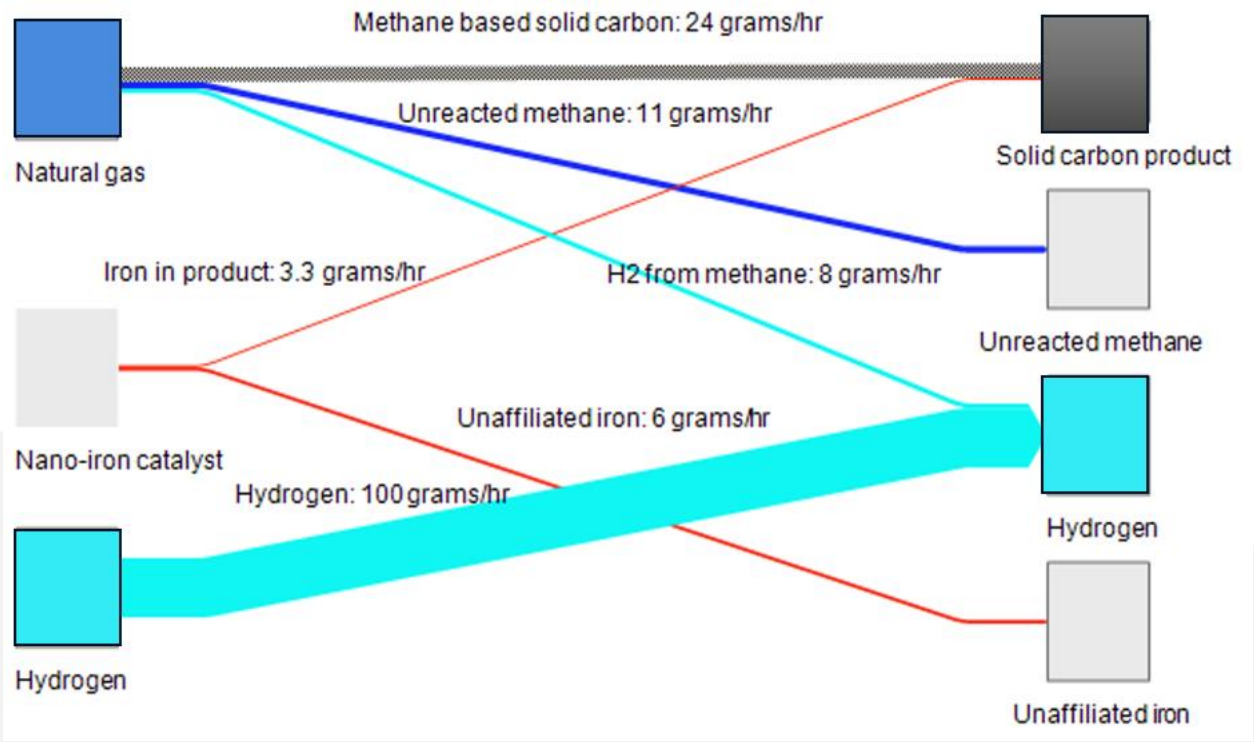
- Hit program technical milepost goals with exception of tensile strength.
- Operating two new R&D Systems.
- Demonstrated robustness to nitrogen and other NG compone
- Derived rate equations and activation energy for the process.

	Target	Achieved
Residual iron	**<10% mass**	**4%**
Strength	**500 MPa**	**400 Mpa**
Single pass CH_4 to H_2 Conversion efficiency	**80%**	**90%**
Net H_2 production	**25%**	**45% (using H2 for energy)**
Net H_2 cost	**< $1.50**	**$1.5 based on $0.5/Kg for carbon**

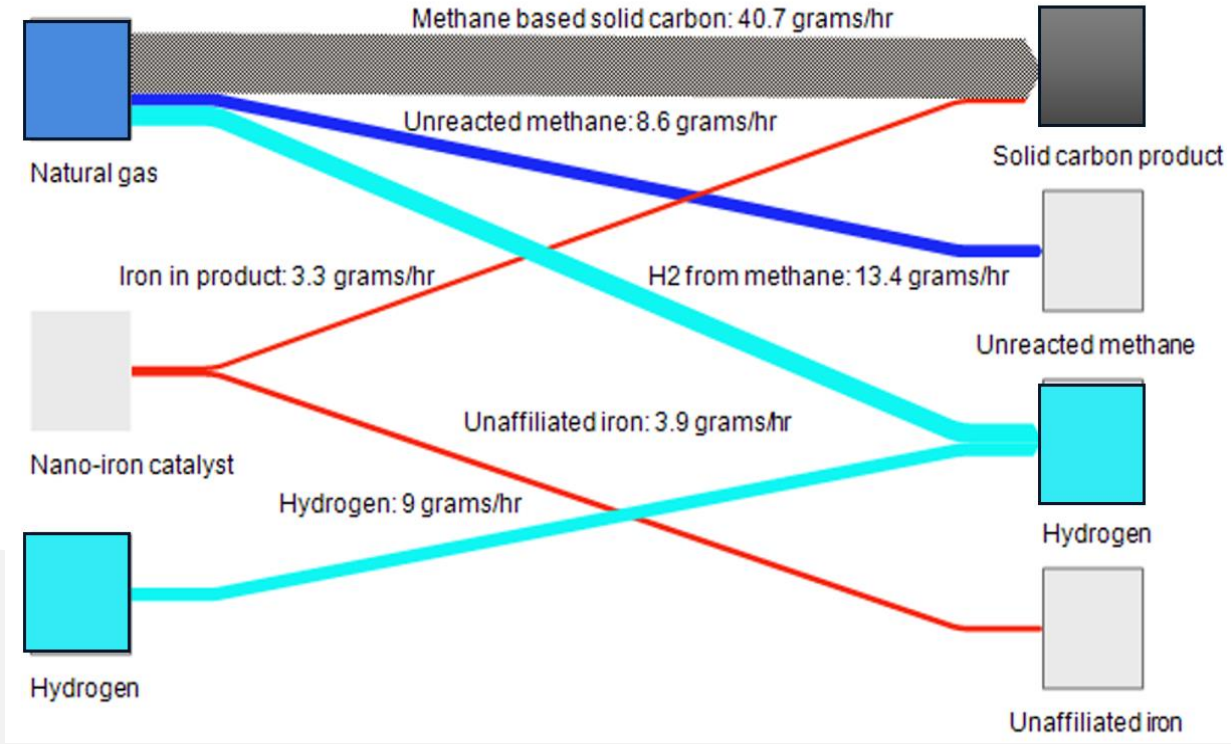


Progress: Conversion efficiency

Initial process



Current best



	Intial	Current best
Conversion Rate	50-60%	>90%
Residual Iron	12-20%	4-10%
H_2:CH_4 Input (volume ratio)	19 to 1	1.6 to 1

Scale-up Tests

- Prototype system was brought on- line to test materials and process issues for scaling
- Exceeded production rate targets but limited campaigns due to fouling.
- Countermeasures are being developed in CFD and tested on a smaller sister vertical system.

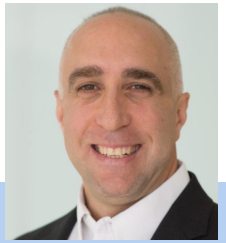
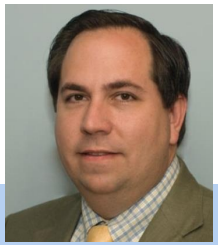
150mm vertical reactor

- Configured to improve solids collection at low carrier gas flow rates.
- Test fouling countermeasures
- Test ex-situ catalysts

System 312: 75mm Reactor

- Improved resolution of residual gas analysis.
- Harvesting carbon product over a wider range of temperatures and pressures.
- Test high pressure feed systems

TEA & Environmental Modeling


Cost modeling

- Using simplified NREL Model*
- Comparison of SMR + CCS, Miralon FCCVD + CCS, and Electrolysis models
- Sensitivity analysis: Regional variation, learning, carbon products, source materials
- Estimates for hydrogen storage and shipping

Environmental modeling

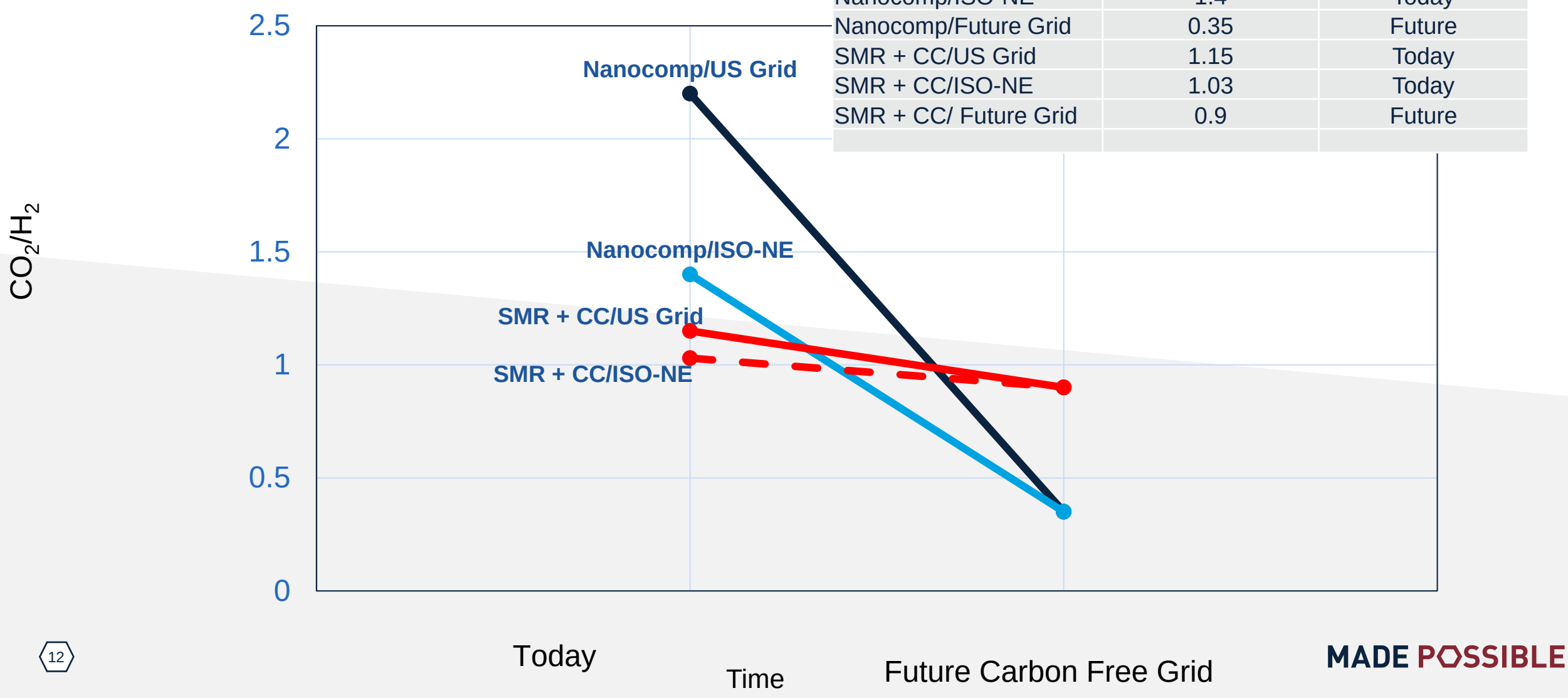
- Estimate CO_2 emitted, emissions avoided, water usage
- **Metrics:** H_2 product out, H_2 utilization mass ratio, H_2 product/fuel energy input, H_2 product/fuel + electricity, EROI
- Sensitivity analysis: Learning curve carbon products, source materials

Based on:

- M&EB and energy balance/flow chart
- Information about the reactor and general system
- Unit cost data from ASPEN
- Carbon capture assumptions for remaining CO_2

Comparision of Miralon process to SMR

Name	CO_2/H_2	Time
Nanocomp/US Grid	2.2	Today
Nanocomp/ISO-NE	1.4	Today
Nanocomp/Future Grid	0.35	Future
SMR + CC/US Grid	1.15	Today
SMR + CC/ISO-NE	1.03	Today
SMR + CC/ Future Grid	0.9	Future



Next Steps

- **Reactor designs**
  - 1000 ton/year system to support ARPAE project goals.
  - 3, 150 and 4500 ton/year systems for Huntsman Flare Program.
  - 54,000 ton/yr system for natural gas decarbonization for COSIA.

Experimentation and applications research

- Tests at Georgia Tech for catalyst optimization and high-pressure operation.
- Carbon material development to hit strength and modulus goals
- Scoping secondary operations needed for commercial products.

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Challenges and Potential Technical Partnerships

Challenge: Megaton scale applications—optimistic but needs substantial work.

Challenge: Catalyst development—significant opportunity for material and energy efficiency and CAPEX reduction.

Looking for:

Partnerships on catalyst , individual consultants or companies.

Partners for applications development

ARPAE large scale commercialization

Partners interested in hydrogen at utility scale

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Thanks to ARPA-E team for continued support.

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